STUDIES IN THE MINERALOGY

OF

CERTAIN SCOTTISH SOILS.

by

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28/6 1929.

PART I:

THE MINERALOGY OF SOILS OF SOUTH-EAST SCOTLAND.

INTRODUCTORY.

The classification of soils has been attempted in a variety of ways, and although it is now generally recognised that climate probably forms the basis of the broadest classifi-cation, yet the geological nature of the parent material is very important, especially in a country like Britain, where the chief problem is the subdivision of the climatic types. In Glinka's scheme of classification (1)*, which is now widely adopted, soils are divided into two groups, an ectodynamomorphic or, mature group, and an endodynamomorphic or, immature group. The influ-ence of the parent material on the soil is still apparent in this latter group and it is with this group that we have to deal in Scotland.

Hall and Russell (2) in a Survey of the soils of Kent, Surrey and Sussex, found that their soil-type boundary lines coin-cided with the boundaries of geological formations, so that they could/

* Numbers in brackets refer to references at end.

could say (p. 4): "all our experience in the field goes to show that each (geological) formation in the area under consideration gives rise to a distinct soil type ------ characterised by its mechanical analysis." It should be noted that texture is the main point considered. The soils of the above area, however, differ much from the rest of Britain. They are mainly residual soils, that is, derived directly from the underlying rocks, wherea the majority of soils in this country are developed from "drift" material, either boulder clay or glacial sands and gravels, and the problem is more complicated in such areas.

The effect of the petrographic nature of the geological formation on the soil was shown by T. Rigg (3) in a survey of an area in which glacial deposits occur, though to a minor extent. He showed that each soil series coincided in area with a geological formation and"that the geological formations give rise to a series of related soils, which exhibit this relationship more closely in the <u>mineral constituents</u> than in the texture." More recently Hendrick and Newlands (4, 5) in a study of certain Scottish and English soils of glacial drift origin showed that the soils could be graded according to the minerals present and that in certain areas the nature of the glacial drift (boulder clay) is almost invariably determined by the kind of rock which had been immediate--ly traversed by the ice.

Ogg (6) has also pointed out that though a broad classi--fication of Scottish soils is possible on a climatic basis, the geologic nature of the parent material must also be taken into account.

References to the development of methods of examining soil minerals may be found in the papers by Hendrick and Newlands, already cited, and also in a paper by H. Loos (7), where besides an extensive bibliography, a detailed description of thirty one soil minerals is given.

The method of analysis used by the writer was as follows: The fine sand fraction got by mechanical analysis of the soil was taken and ignited. The minerals present were first separated into two groups according to specific gravity, the liquid used being bromoform. This gives two groups of minerals, one of specific gravity greater than 2.9, the other lower. The first group is found to contain mainly iron oxides and the ferro-magnesian silicates, and the second, quartz, feldspars, and also flaky minerals like the micas and weathered ferro-magnesian sili--cates which remain in the lower group by reason of their habit or lowered density through weathering, though their density when fresh would put them in the heavy group. The lighter group is then separated into two fractions, one of specific gravity greater than/

than 2.6, the other lower. Bromoform is diluted with zylol to a suitable density for the latter separation. Resort is made to the electromagnet to remove the micas and the weathered ferro-magnesian silicates from the lighter groups.

The three fractions, one of specific gravity less than 2.6, the second of specific gravity greater than 2.6 and less than 2.9, and the third of specific gravity greater than 2.9 are, in theory, characterised by orthoclase, quartz and plagioclase, and ferro-magnesian silicates respectively but in practice it is very diffi-cult to obtain a clean separation of the lighter groups. This difficulty is caused by the fact that the difference in specific gravity between orthoclase (2.56) and quartz (2.65) is only 0.09, while the plagioclases range from 2.62 to 2.75. The presence of inclusions in such cases also render the separation difficult. The percentage figure obtained for the heavy group is much more satisfactory.

The "coarse sand" and "silt" fractions of the mechanical analysis were also examined for comparative purposes, but no attempt was made to separate the minerals, the silt fraction not being capable of grading by ordinary gravity separation, owing to surface tension effects. A separation of the magnetic minerals can, however, be made by means of the electro-magnet.

The area from which the soils were taken for this study lies between the Rivers Forth and Tweed and comprises the counties of West Lothian, Midlothian, East Lothian, Berwickshire, Roxburgh-shire, Selkirkshire and Peebleshire.

PHYSIOGRAPHY.

This area forms the eastern part of two of the topo-graphic divisions of Scotland, the Midland Valley and the Southern Uplands. Along the Forth and stretching east and south along the coast is a low-lying plain, sometimes stretching for several miles inland and at other times, especially in Berwickshire being con-fined to a narrow coastal strip. From this plain there is a gentle slope to about 750 feet. This part is also variable in extent and is diversified in the west by the Bathgate and the Pentland Hills and in the east by the Garlton Hills. Beyond this come the Moorfoot and Lammermuir Hills, which here form the northern boundary of the Southern Uplands. These have a varying breadth of five to ten miles and an average height of about 1500 feet. They are succeeded by the valley of the Tweed, with a to-pographic character similar to that already described for the Forth but much narrower in extent.

Two distinct types of cultivation are to be found in the area: in the low ground, arable and in the higher, especially in the Moorfoots and Lammermuirs, pasture.

GEOLOGY.

Descriptions of the geology of this area may be had in the maps and memoirs published by the Geological Survey for Scotland (8, 9). The following rock groups occur:

Pleistocene and Recent.	Peat Alluvia Raised Beaches Glacial Sands and Gravels Boulder Clay.
Carboniferous.	
Old Red Sandstone.	Upper Lower
Silurian	Upper Lower (Ordovician).

The Silurian rocks consist mainly of shales, grits, and greywackes, while the Old Red Sandstone is characterised by sand--stones, marls, conglomerates and associated igneous rocks. All the Carboniferous Series up to the Coal Measures are represented, and of these the Calciferous Sandstone and the Carboniferous Limestone cover the largest area. There is also a large develop--ment of lavas and tuffs, especially of Lower Carboniferous age.

Overlying these rocks there is a coating of glacial drift/

drift, boulder clay and glacial sands and gravels, of varying thickness. It is deepest in the low-lying ground and thins to the hills. Round the Firth of Forth and on the sea-coast occur raised beaches, while alongside the principal rivers are stretches of alluvia. Peat is very extensively developed on the Moorfoot and Lammermuir Hills.

The physical features of the area are a reflection of the geology. In the northern part the hills consist of igneous rocks, while the Moorfoot and Lammermuir Hills are carved out of highly folded Silurian sediments. In all cases the rocks of the hills have been much more resistant to weathering than the softer sediments of Carboniferous and Old Red Sandstone age.

DESCRIPTION of SOILS.

Climatically there are two divisions in the area, one of a rainfall under 30 ins. and the other of a rainfall of be--tween 30 and 40 ins. The first area is confined to a narrow strip at the coast. This grouping has been used by Ogg (6) in his general classification of Scottish soils but no detailed sub-division on a climatic basis is possible yet. In the present study soils overlying the various geological formations represen--ted in the area were taken to determine the mineralogical differences present, if any, and also the state of weathering of the minerals.

All the above soils* are developed on glacial drift, the majority on boulder-clay but No. 4 is formed on glacial sands and gravels.

* See Map at end for location of soils.

TABLE I.

List of Soils Examined.

Soil	Locality	Description of surface soil	Geology
		Group I.	
1	Synton Mains, Selkirkshire	Buffy brown silty loam, stoney	Glacial drift over Lower Silurian
2	Blackcastle Hill, Selkirkshire	Buffy brown medium loam	Glacial drift over Lower Silurian
3	Synton Mill, Selkirkshire	Grey brown loam, gravelly	Glacial drift over Lower Silurian
4	Easter Langlee, Berwickshire	Reddish brown loam, slightly gravelly	Glacial drift over Lower Silurian
5	Spottiswood, Berwickshire	Buffy brown gravelly loam	Glacial drift over Upper Silurian
6	Flass, Berwickshire	Olive brown loam, stoney	Glacial drift over Upper Silurian
		Group II.	
7	East Mendick, Peebleshire	Fuscous black peaty soil, gravelly	Glacial drift over Lower Old Red Sandstone
8	New Kaimhouse, Peebleshire	Bister brown loam, clayey	Glacial drift over Lower Old Red Sandstone
9	Temple Mains, East Lothian	Reddish brown clayey loam	Glacial drift over Upper Old Red Sandstone
10	Innerwick East Lothian	Brown friable loam	Glacial drift over Upper Old Red Sandstone
11	Bassendean Berwickshire	Reddish brown clayey loam	Glacial drift over Upper Old Red Sandstone

TABLE I (contd).

Soil	Locality	Description of surface soil	Geology
		Group III.	
12	Pylafoot, Roxburghshire	Olive brown silty loam	Glacial drift over Basalt (Carboniferous)
13	Kersmains, Roxburghshire	Brown medium loam	Glacial drift over Basalt (Carboniferous)
14	Boghall, Midlothian	Chocolate and brown loam	Glacial drift over Basalt, (Old Red Sandstone)
15	Yellow Craigs, East Lothian	Olive brown loam	Glacial drift over Trachyte, (Carboniferous)
16	Abbey Mains, East Lothian	Reddish brown loam	Glacial drift over Trachyte Tuff, (Carboniferous)
17	Bankhead, West Lothian	Grey brown medium loam	Glacial drift over Tuff, (Carboniferous)

TABLE I (contd.).

Soil	Locality	Description of surface soil	Geology
		Group IV.	
18	Ugstonrigg, East Lothian	Buffy brown loam	Glacial drift over Calciferous Sandstone Series
19	Alderston, East Lothian	Olive brown medium loam	Glacial drift over Calciferous Sandstone Series
20	Weird's Wood, East Lothian	Cinnamon brown loam, gravelly	Glacial drift over Calciferous Sandstone Series
21	Moffat Wood, East Lothian	Dark grey brown loam	Glacial drift over Calciferous Sandstone Series
22	Samuelston, East Lothian	Reddish brown loam	Glacial drift over Calciferous Sandstone Series
23	Pyothall, West Lothian	Grey brown loam	Glacial drift over Calciferous Sandstone Series
24	Swinton Mill, Berwickshire	Snuff brown gravelly loam	Glacial drift over Calciferous Sandstone Series
25	Simprim, Berwickshire	Umber brown silty loam	Glacial drift over Calciferous Sandstone Series
26	Leithholm, Berwickshire	Olive brown medium loam	Glacial drift over Calciferous Sandstone Series

TABLE I (contd).

Soil	Locality	Description of surface soil	Geology
		Group V.	
27	Salton, East Lothian	Chocolate and brown loam	Glacial drift over Carboniferous Limestone Series
28	Oxwell Mains, East Lothian	Reddish brown loam	Glacial drift over Carboniferous Limestone Series
29	Skatterraw, East Lothian	Reddish brown loam	Glacial drift over Carboniferous Limestone Series
30	Pathhead, Midlothian	Friable brown loam	Glacial drift over Carboniferous Limestone Series

MECHANICAL ANALYSIS.

The mechanical analyses of soils from this region have been studied by Gracie (10) and Nos. A, B, C, Table II., are taken from his paper. A few representative analyses are given in Table II.

It will be seen that the clay content is fairly high but it is typical of soils of this area developed over glacial drift. All these soils are derived from boulder clay and naturally the clay content is higher than it would have been for such soils developed on glacial sands. In the detailed study later it will be seen how this affects the soil texture. The fine sand fraction in every case forms a fairly high proportion of the "fine earth" and since this is the material taken for the mineralogical analysis it may be taken as typical of the "fine earth" fraction of the soil.

TABLE II.

	A.	B.	C.	D.	E.	F.	G.
Fine gravel	13.40	7.49	5.47				
Coarse sand	13.76	20.55	24.75	18.70	19.15	24.89	17.65
Fine sand	27.17	20.82	29.23	30.04	39.76	31.38	31.19
Silt	10.70	9.78	5.70	9.00	7.77	11.44	8.62
Fine Silt	11.10	15.00	8.13	12.33	10.76	12.16	11.71
Clay	5.70	9.75	7.75	19.65	12.00	12.82	11.13
Moisture	4.54	4.09	4.09	2.77	2.59	2.43	10.81
Ignition Loss	12.82	11.09	12.48	6.77	6.74	5.62	8.26
Total	99.19	98.57	97.60	99.26	98.77	100.74	99.37

Soil.	Locality.	Geology.
A.	Kidlaw, East Lothian.	Glacial drift over Lower Silurian.
B.	Humbie, East Lothian.	Glacial drift over Lower Silurian.
C.	Innerwick, East Lothian.	Glacial drift over Upper Old Red Sandstone.
D.	Moffat Wood, East Lothian.	Glacial drift over Calciferous Sandstone series.
E.	Bolton, East Lothian.	Glacial drift over Calciferous Sandstone series.
F.	Boghall, Midlothian.	Glacial drift over basalt (Carboniferous)
G.	Pathhead, Midlothian.	Glacial drift over Carboniferous Limestone series.

MINERALOGICAL ANALYSIS.

TABLE III.

Results of analyses of fine sand fractions, given as percentages.

Soil.	Orthoclase group.	Quartz group.	Ferro-magnesian silicate group.
		Group I.	
1.	1.7	94.4	3.9
2.	2.4	93.5	4.1
3.	.9	97.1	2.0
4.	4.7	92.6	2.7
5.	.9	94.6	4.5
6.	.5	97.7	1.8
		Group II.	
7.	2.2	95.2	2.6
8.	1.9	97.0	1.1
9.	.7	96.0	3.3
10.	2.4	94.6	3.0
11.	.7	98.0	1.3
		Group III.	
12.	3.2	94.7	2.1
13.	3.4	93.5	3.1
14.	4.3	89.2	6.5
15.	2.6	95.2	2.2
16.	1.5	94.4	4.1
17.	37.5	58.0	4.5

TABLE III. (contd).

Soil.	Orthoclase group.	Quartz group.	Ferro-magnesian silicate group.
		Group IV.	
18.	1.6	96.5	1.9
19.	1.2	93.3	5.5
20.	.4	97.6	2.0
21.	2.8	94.9	2.3
22.	1.6	95.1	3.3
23.	1.7	92.4	5.9
24.	1.1	96.1	2.8
25.	1.6	95.3	3.1
26.	1.4	94.3	4.3
		Group V.	
27.	2.1	96.0	1.9
28.	2.2	95.1	2.7
29.	3.0	90.3	6.7
30.	1.9	97.0	1.1

MINERALOGICAL ANALYSIS.

From the above list in Table III it will be seen that there is a distinct variation in the ferro-silicate percentage of soils developed from similar geological material but it is only to be expected that there are local concentrates in the drift deposits as in sediments. Also the varying textures of the glacial drifts affect the rate of percolation of atmospheric waters and thus affect the rate of solution of the minerals. Different degrees of cultivation may also have some effect. From these analyses the only broad generalisation is that the soils over igneous rocks have the higher ferro-silicate percentage. There does not seem to be any differentiation between the soils over Old Red Sandstone sediments and over Carboniferous sediments as had been found by Hendrick and Newlands in their study of soils from other parts of Scotland (5, p. 266), though on the whole the percentages for soils over the Carboniferous are higher. The high percentage for the Orthoclase group in No. 4 is due to the presence of rock fragments, while in the case of No. 17, the re-markably high figure is due to the mineraloid palagonite.

Table III should be compared with Table IV, in which lists of the minerals found are given. The frequency of the oc-currence of the minerals is indicated by the numbers, 1 meaning most frequent, 2, 3, 4, etc., indicating decreasing frequency. The numbers are not relative for different soils but only for a particular soil.

TABLE IV.

Mineral suite - other than quartz.

	Group I.						Group II.					Group III.					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Plagioclase	3	1	2	2	1	3	1	2	1	3	3	1	1	1	1	4	2
Orthoclase & Microcline	4	6	4	5	5	4	7	3	4	2	1	2	3	5	3	2	4
Iron-oxides	1	3	3	3	3	1	2	1	2	1	2	3	2	2	2	1	3
Augite	5	5	-	4	4	-	4	4	3	6	5	4	4	3	4	3	5
Enstatite	-	-	-	-	-	13	-	-	13	-	11	6	10	-	-	-	12
Hypersthene	-	-	-	12	-	-	-	-	14	8	-	13	-	-	-	-	13
Hornblende	9	4	6	8	7	6	6	9	5	-	10	-	11	7	9	-	10
Biotite	6	8	5	6	6	7	-	11	6	4	8	5	9	4	5	7	6
Muscovite	7	9	7	9	8	8	-	12	7	-	-	-	-	-	6	6	7
Epidote	-	-	-	-	-	11	-	8	-	-	-	-	-	-	11	-	-
Apatite	-	-	-	-	-	-	-	-	12	-	9	7	5	9	-	-	-
Garnet	10	-	9	10	9	5	3	5	9	7	6	8	6	8	8	5	9
Zircon	11	10	10	11	11	10	8	6	8	5	7	9	7	6	10	9	8
Tourmaline	8	7	8	7	10	9	5	7	10	-	4	10	8	11	7	8	11
Rutile	12	11	-	12	12	-	-	-	11	-	12	11	-	12	-	-	-
Staurolite	-	-	-	-	-	12	7	10	-	--	-	-	-	-	-	-	-
Chlorite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Palagonite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Rock frag- -ments	2	2	1	1	2	2	-	-	-	-	-	-	-	-	10	-	10	-

TABLE IV. (contd).

	Group IV.									Group V.			
	18	19	20	21	22	23	24	25	26	27	28	29	30
Plagioclase	1	1	1	2	1	3	2	3	1	2	2	3	6
Orthoclase & Microcline	3	4	3	3	4	4	3	1	3	4	3	4	4
Iron Oxides	2	2	2	1	2	1	1	2	2	1	1	1	1
Augite	4	3	4	4	3	2	4	4	4	3	4	2	2
Enstatite	-	8	-	-	-	-	13	13	8	10	-	12	-
Hypersthene	-	-	-	10	-	11	-	-	-	-	-	15	-
Hornblende	8	10	-	8	-	5	12	14	13	-	-	13	-
Biotite	6	6	5	-	-	8	6	6	6	6	7	5	5
Muscovite	7	7	6	-	-	9	7	7	7	9	-	6	-
Epidote	12	12	-	-	-	-	-	-	-	-	8	11	-
Apatite	-	-	-	-	-	13	11	10	12	11	-	14	-
Garnet	5	5	-	6	5	7	8	8	9	5	5	7	3
Zircon	10	9	8	5	7	12	9	9	10	7	6	8	6
Tourmaline	11	11	7	7	6	10	10	11	-	-	-	10	-
Rutile	9	-	-	9	8	14	-	12	11	8	-	9	-
Staurolite	-	13	-	-	9	-	-	-	-	-	-	-	-
Chlorite	-	-	-	-	10	-	14	-	-	-	-	-	-
Palagonite	-	-	-	-	-	-	-	-	-	-	-	-	-
Rock fragments	12	-	-	11	11	-	-	-	14	12	-	-	-

DESCRIPTION of the MINERALS in the FINE SAND FRACTION of the SOILS.

(see Plate I.).

Quartz is the most abundant mineral in all the soils. It occurs in angular grains, often clear but generally spotted with iron-oxide inclusions along cracks. Inclusions of fluid and rutile are also common.

Plagioclase is very common in all the soils but varies in amount. It is very common in the soils overlying the igneous rocks of Carboniferous age, especially the more basic types. It is practically always turbid, that is showing signs of chemical decomposition: it is very infrequently fresh. The grains are generally quadrate in shape.

Orthoclase is also fairly common. It is fresher always than plagioclase but is generally slightly turbid. Like plagio--clase it occurs in quadrate grains and does not show the irregular outline as in quartz. Microcline is fairly common in soils over the Old Red Sandstone and the Carboniferous areas, but is not nearly so common in the Silurian areas. It is always fresh.

Iron-oxides are generally the commonest minerals in the heavy residues. Limonite and ilmenite changed to leucoxene are the/

the most frequent, but haematite, ilmenite and magnetite also occur, the latter being the commonest of the three. The limonite and haematite occur in earthy form.

Augite is present in all the soils, sometimes very fresh, at other times weathered. It occurs in greeny brown grains of rather large size, angular and prismatic in shape. The titani-ferous variety is fairly common in certain of the soils from Carboniferous areas.

Enstatite occurs as rather small greyish prismatic grains. It is rather infrequent and is commonest in the soils from Carboniferous areas.

Hypersthene was only noted in seven of the soils and is most frequent in those over Carboniferous rocks. It is brownish, pleochroic and prismatic in habit.

Hornblende occurs in rather small angular and prismatic grains; green generally but brown varieties and also a peculiar cinnamon-brown type occur. It is practically always fresh.

Biotite and muscovite are present in every soil. They both occur in rounded plates, the biotite usually brown but sometimes green and the muscovite colourless. The brown biotites are generally bleached. Inclusions are common.

Epidote has only been occasionally met with in certain of the soils. It occurs in yellow-green grains, pleochroic, and generally ovoid in shape.

Apatite was only noted infrequently. It occurs as aci--cular needles and also as rounded grains.

Garnet has been noted in practically every soil examined. Brown, pinkish-brown and colourless varieties are met with, the two latter often in association. The grains are usually angular or sub-angular and of large size, and occasionally show cleavage.

Zircon. Complete crystal forms to ovoid grains are present, the former being very infrequent. Varieties with prism and pyramid termination developed, the other end being broken, have been met with. The ovoid grains are commonest and are fre--quently dusky. Zoned varieties have also been noted.

Tourmaline. Brown, greenish and also blue varieties have been noted, but the latter are very infrequent. Prismatic forms, with end terminations are fairly frequent but rounded forms are commonest. A feature of the tourmalines in the soils developed over Carboniferous rocks is the presence of both com--pletely prismatic types and completely rounded types.

Rutile/

Rutile is not of very frequent occurrence in the soils. It is generally deep brown but the yellow-brown variety has also been noted. It is irregular in habit. No twins have been seen.

Staurolite has only been found in a few of the soils. It occurs in rather large rounded grains with a golden brown colour.

Palagonite. This mineraloid was noted in only one soil. It is brown in colour, with a specific gravity below 2.6 and re-fractive index of about 1.47. It contains inclusions, which have not been determined. The grains are irregular in shape and highly angular.

Chlorite has only been found in soils from the Carboni-ferous areas. It occurs as rounded green grains.

Rock fragments are especially common in the soils over Silurian rocks. They are micro-felsitic in character.

The soils in general contain a large proportion of ferro-magnesian silicate minerals, which are comparatively fresh, that is only slightly altered chemically, and having a large reserve of bases.

MINERALS and PLANT FOOD.

Potash, phosphate and lime are the important constituents of minerals to agriculture. Chemical tests can readily determine the presence of such substances in the soil but more important still is to determine the availability of them for plant food-stuffs. Plummer (11), who has investigated the solubility of various potash-bearing minerals in carbonated water found the following order of solubility: biotite, muscovite, orthoclase, microcline. In the soils examined all these minerals have been found, though in varying amounts. The freshness, which is an in--dication of the chemical alteration, is least in biotite and greatest in microcline which would support the above conclusion, though muscovite has always been found fresh. There would seem to be, therefore, an appreciable supply of potash in all the soils but since orthoclase is in general a commoner mineral in the soils than the micas the potash may not be readily available.

The principal phosphate-bearing mineral found is apatite and this has only been noted in many of the soils over the Carboni--ferous area and infrequently in the others. Its presence and amount, however, is sometimes difficult to judge since it is necessary in certain cases to clean the soil grains with dilute acid and apatite goes readily into solution.

Plagioclase/

Plagioclase, augite, hornblende, garnet and epidote are the main lime-bearing minerals present. The two latter may be neglected since they are very resistant to weathering. Augite and hornblende have been found remarkably fresh, though the augite is generally slightly weathered. Plagioclase, however, is practically always in every soil turbid, that is altered chemically. The soils contain a fair proportion of lime-bearing minerals.

RELATION of SOILS to GEOLOGY.

It has already been noted that the soils over Silurian rocks are peculiar in the large amount of rock fragments present in the fine sand fractions. These fragments are micro-felsitic in character and would seem to denote that the weathering processes have not gone so far in the soil material as in the case of the other soils. The slight metamorphism to which the Silurian rocks have been subjected may account for this. The paucity in orthoclase is also another feature of the mineralogy of these soils.

The soils over the Old Red Sandstone areas are marked by the angularity of the grains though this is not always the case and garnet is generally the distinguishing mineral though it has not/

not been found so common in these soils as Hendrick and Newlands (5) found it in the north of Scotland. The soil from Innerwick(No 10) is peculiar in that the minerals of the ferro-silicate group are mainly iron-oxides, limonite and haematite being the commonest. This soil has been very intensively cultivated for a long time and the mineral content may be a reflection of the aeration and continued application of artificial manures to the soils.

Soils of groups II and III are from Carboniferous areas but differ in that the first are developed over igneous rocks while the second are over sediments. The higher ferro-silicate content is generally sufficient to distinguish them but this is not invariably the case. In the first group though the mineral suite is practically the same throughout, the presence or the abundance of a certain mineral may serve as a distinguishing character. The Boghall soil (No. 14) has a similar mineral suite to the Roxburghshire soils (Nos. 12 and 13): these three soils being developed over basalts. Soils Nos. 15 and 16 have a large amount of orthoclase present: they are developed over trachyte and trachytic tuff respectively. Soil No. 17 is peculiar in the high percentage of palagonite it contains. The soil lies on a palagonite tuff, previously mapped as a basaltic tuff, and is practically/

practically residual there being only a thin skin of drift over the solid rock. In soil No. 21 from West Lothian there occurs a type of hornblende (cinnamon brown in colour) which is typical of the quartz-dolerites lying to the west. In the soils of this district also certain brown decomposition products are found, pro--bably mineraloid in character, but it is not known from what mineral they arise.

The mineral suite of the soils from the Carboniferous areas is practically identical with that of Hendrick and Newlands (5, p. 264) from other Carboniferous areas, augite and hypersthene being the distinguishing minerals. In the soils so far examined the results would indicate that the soils of the Carboniferous Limestone areas may be distinguished from the Calciferous Sand--stone areas by the more frequent occurrence of garnet in the former but an insufficient number of soils have been investigated to be positive on this point.

The above results would indicate a variation in the mineral content of the glacial drift, since all the soils are de--rived from drift material and that this mineral variation is determined by the geological formation underlying the drift. In the area examined the general movement of the ice has been from west/

west to east so that in certain cases there is an overlap of material, as in the case of certain West Lothian soils but gener--ally the underlying rocks have the main influence in the petro--graphic character of the drift. In the case of East Lothian this variation has been noted by the Geological Survey in the Memoir (9, p. 171), in which comment is made on the difference in colour and texture of the boulder clay according to the underlying geological formation. Practically all the minerals of the soils are to be found in local rocks and extraneous minerals such as staurolite and tourmaline, which may have been derived from erratics, are infrequent and there is also the possibility that they may have been derived from local sediments since they have been recor--ded in sandstones of the Midland Valley by Bosworth (12).

MINERALOGY of the SOILS and CLASSIFICATION.

In the previous section it was shown that the soils had different mineral content according to the different geological formation underlying the boulder clay from which the soils were derived. Thus in the south-east of Scotland the soils can be related petrographically to the underlying rocks through the drift. This is of course not expected to hold always, especially if the outcrops of rocks at right angles to the direc--tion of ice movement are narrow and the drift thick. In regions of complex geology also the drift may be expected to be very varied. But where, as in south-east Scotland, extensive areas of similar rock formation occur the mineral constitution of the drift approximates to that of the underlying rock. A determination of the mineralogy of the matrix of the drift would in such cases be useful in determining, first, the distribution of the drift, and, second, in forming a basis for grouping the soils.

PART II:

THE GEOLOGY AND MINERALOGY OF THE SOILS OF THE EXPERIMENTAL FARM, BOGHALL, MIDLOTHIAN.

The present study is a detailed investigation of the geology and mineralogy of the soils of a small area, specially selected because of the varied geology of the parent material. The rocks of the district are very diverse and are mainly overlain by a covering of glacial drift, which is itself varied in character. Partly because of this and partly because of the topography the soils are very varied. The area comprises a farm at Boghall, Midlothian, Scotland, owned by the Edinburgh and East of Scotland College of Agriculture and is typical of many Scottish hill-foot farms, consisting of a cultivated area at the base of the hill and a sheep-run stretching to the top.

PHYSIOGRAPHY.

The Experimental Farm, Boghall, Midlothian, lies to the south-west of Edinburgh on the south-east slope of the Pentland Hills. The acreage is about 600, of which 200 are given over to arable land and the remainder to pasture.

The arable land is rolling in appearance and rises from 500 feet at Seafield to 700 feet at the Steading. The mounds trend/

trend roughly north-east to south-west.

The pasture land rising from 700 feet to 1615 feet con-sists of the glen, the bottom of which is fairly flat, and the actual hill slopes of Allermuir and Caerketton Hills which are steep. From the Steading the land rises gradually to the north-west till about 1250 feet, where the slope to Caerketton Hill then steepens. This is also the case in the glen itself, so that on the south and south-west slopes of Caerketton and on the southern slopes of Allermuir Hill, screes appear at about 1250 feet. The flat bottom of the glen, most extensive at the base of Allermuir Hill, is diversified at the lower end by mounds of gravel banked on the side of the hill and cut by two small streams running into the main burn.

CLIMATE.

A general account of the climate of Midlothian is given by McCallum (13).

The county, by reason of its topography, is divided into two well-marked climatic areas, one a region of rainfall less than 30 in. and the other of rainfall from 30 in. to 40 in. Boghall lies in the second region. Climatic records at the farm only extend from 1925, so that no figures for a long period can be given./

given. The annual rainfall from 1925-8 averaged 38.7 in., while the average rainfall at Edinburgh over a long period is only 25.4 in., but over the whole county great variations occur, caused by variations in altitude. The sunshine averaged 3.7 hours per day over the period 1925-8 while the average monthly temperature for the same period was 46.5° F.

GEOLOGY.

A general description of the rocks of Midlothian in which the farm is situated has been published by the Geological Survey of Scotland in their Memoir, The Neighbourhood of Edinburgh (8). The solid rocks of the farm area belong to the Lower Old Red Sandstone and the Carboniferous formations, and these are partly overlain by a series of glacial sands, gravels, and clay.

Formations and Rock Groups.

The geological formations occurring in the area are:

1. Pleistocene and Recent	Peat. Alluvia. Glacial sands and gravels. Boulder clay.
2. Carboniferous	Calciferous Sandstone series.
3. Lower Old Red Sandstone	Lavas. Tuffs.

The rocks of Lower Old Red Sandstone age are most ex--tensive and stretch from Allermuir Hill through Caerketton to a point about 300 yards north-west of Seafield. They are volcanic rocks, being a series of lava flows and tuffs dipping roughly to the south-east. They are of varied character and may be grouped as follows, starting from the youngest:

(a) Allermuir group of basic andesites and basalts.

(b) Caerketton group of rhyolitic lavas, acid andesites, trachyte and tuff.

(c) Caerketton group of basalts and basic andesites.

All these rocks are in a highly decomposed state and many secondary minerals have been developed in them. A detailed account of the rocks is given in the Memoir (8), p. 29.

The Allermuir group of basalts and andesites is dark red in colour, being heavily stained with iron oxides. The olivine and augite have decomposed. Haematite, chlorite and calcite are the secondary minerals developed.

The Caerketton rhyolite has been completely silicified though the original rock structure has been retained. It is com--posed of fine-grained felsitic material.

The trachyte included in this band contains biotite and sanidine, while zircon, iron oxides and apatite are found in the ground mass./

ground mass.

The third group of lavas resembles the Allermuir group but is more basic in character. Olivine is represented by pseudo--morphs and plagioclase felspar is very abundant. Augite and hypersthene andesites also occur. Decomposition products such as iron oxides, chlorite and calcite are present.

The Upper Old Red Sandstone is not represented in this area, and the junction between the lavas and the Carboniferous formation is here a reversed fault, the Pentland Fault, which sepa--rates the Pentland Hills from the Midlothian coal-field to the east. On the farm ground the position of the fault can only be inferred, since the ground is obscured by drift deposits. The rocks to the south of the fault consist of sandstones and shales belonging to the Calciferous Sandstone series, that is, the lowest group in the Carboniferous formation.

During the Glacial Period Midlothian was invaded by ice from the north-west, but it was also affected by ice from the south. The ice from the north-west completely covered the Pent--land Hills and left as relics a deposit of boulder clay, erratics, sands and gravels.

From the map* it will be seen that a great part is covered by these drift deposits, and it is only on the higher ground/

* See geological map at end.

ground that the bed-rocks are seen. But even here on the hill tops, where the soil at present is very thin and rests on shattered rock, glacial material may well have been spread at one time and then mostly removed by subsequent denudation, as is indicated by a soil analysis quoted later. Bennie (14) has described the finding of a boulder clay on the top of Allermuir Hill, but this has not been confirmed.

The Boulder Clay.

The boulder clay is the most extensive glacial deposit and covers most of the ground from Seafield to the base of Allermuir, although in part it is covered by later deposits. It is fairly uniform in texture but tends to be sandier on the hill slopes. Two isolated patches of it occur on the side of Caerketton Hill, indicating probably a greater extent at one time.

In the glen good exposures of the clay can be seen and it is there reddish-brown in colour, and for a boulder clay, fairly loose in texture. The included stones are not large in size and consist mainly of fragments of lavas of the Pentland Hills, with a subordinate amount of quartzite, schists, grits, sandstones, and shale. The quartzites and schists are derived probably from the South-west Highlands. At the Seafield end of the farm the clay is greyer in colour and there is a greater amount of sandstone, shale and coaly material, but the Pentland lavas are still prominent.

The/

The boulder clay here overlies rocks of the Carboniferous formation.

Sands and Gravels.

Overlying the boulder clay occur two large spreads of sands and gravels, one on the arable land, the other in the glen. The spread to the south of the road forms a series of mounds trending north-east to south-west. It is very variable in charac--ter, having patches of gravel with intervening lenticles of sand, and at other parts clay. This is well seen after ploughing, when the furrows stand up well in the clayey parts but not so well in the others. The pebbles in the gravel vary in size from ordinary gravel to stones about 3 in. in diameter. As in the boulder clay the predominant pebbles are local lavas, but sandstones, shales, quartzites, schists, grits and coal are also present. There is no well-marked transition here from the gravel to the boulder clay, and the gravelly nature of the ground to the south-east may well be due to weathering of the clay and local segrega--tion of the boulders.

The gravel-spread in the glen overlaps the boulder clay and is itself overlapped by hill-wash from Caerketton Hill and Allermuir Hill. It is much stonier than the lower spread and the predominant pebbles are lavas. In both spreads the stones are markedly rounded in contrast to the angular stones of the scree and the boulder clay.

Post-Glacial Deposits.

Alluvium. The burn which runs down the glen has in parts cut its way down through the boulder clay to expose the bed-rock. Two streams, flowing into the burn from the north-west have also dissected the boulder clay. In its upper part the gradient of the burn is such that no material is deposited and erosion is still going on. In the field, however, the gradient is very much lessened so that behind the Steading and extending along the banks of the stream to Seafield occurs a spread of allu--vium. In the more easterly part the alluvium is of a silty character, but at the Steading it is of the nature of an alluvial fan with much stony material. To the north-west of this fan the ground rises slightly to form a small flat which probably consists of alluvial material laid down by the flooding of the burn. Similar fans may be seen in process of formation at the confluences of the two tributary streams to the main stream in the glen.

At the head of the glen on the slope of Allermuir Hill there are two small patches of alluvium consisting mainly of hill-wash, and in a small hollow on the south slope of Caerketton a similar deposit occurs.

The scree material. As one ascends Caerketton Hill from the road and crosses the belt of boulder clay, the surface of the ground is seen to get stonier, the stones being very angular. These/

These have been derived from material slipping down the hill. Off the boulder clay and forming an extensive belt at the plantation the scree material is mixed with hill-wash and is more than 1 ft. thick. Higher up the hill occurs another belt of scree but much thinner and with less soil. The scree material here, of course, is basaltic and andesitic in character, so that with the reservations already made, the soils are practically residual.

Further up the glen the same features can be observed on the slopes of Caerketton and Allermuir Hills, the steep brow of Caerketton standing out prominently at one point with its white screes. At the base of Allermuir Hill the screes are very thick and have formed a shoulder overlapping the boulder clay.

At various points among the scree, bare rock sticks out, but this occurs nowhere else on the farm. The soil is thin and in the higher parts the screes are still unstable.

<u>Peat</u>. On the tops of Allermuir Hill and Caerketton Hill peat occurs, but it is very thin and at no part thicker than about 6 in. There is generally very little mineral soil on the flat tops, but it is present on the basaltic slopes under the peat. The screes of Caerketton Hill have a peaty matrix. Pat--ches of peaty soil also occur in the hollows between the mounds on the arable ground.

DESCRIPTION of SOILS.

In Table I is given a list of the soils examined and their localities, with a note on the underlying rock formations. It will be noted that with the exception of one soil (Sample I), all the soils are derived from drift material. Chemical data on certain of these soils are given by Smith (15) and Ogg and Dow (16).

TABLE I.

List of soils examined.

Soil	Locality	Description of surface soil	Geology
A.	Croft's Field	Brown and chocolate, sandy loam	Alluvial fan over basalt
B.	Cow Loan	Brown and chocolate, red loam, fairly heavy	Alluvial flat over basalt
C.	Kimming Hill	Fine, sandy, brown loam	Glacial sand and gravel over basalt
D.	Hay Knowes	Red and chocolate, gra--velly loam	Glacial sand and gravel over basalt
E.	Lambing Field	Dark brown, light loam	Glacial gravel and scree over basalt
F.	Hill Field	Chocolate and brown loam	Thin boulder clay over basalt
G.	House Park	Chocolate and brown loam	Boulder clay over basalt
H.	Glen	Brown loam	Boulder clay over acid andesite
I.	Caer-ketton	Dark brown, peaty soil	Scree and glacial gravel over acid andesite
J.	Glen	Cinnamon browm, fluffy loam	Thin glacial gravel over boulder clay, overlying basic andesite
K.	Sea-field	Fine, brownish loam	Boulder clay, over sand-stone (Carboniferous)
L.	House Park	Chocolate and reddish, compact gritty clay	Boulder clay over basalt.

Mechanical Analysis.

The results of the mechanical analyses of the soils, made according to the method of the Agricultural Education Association (17) are given in Table II.

The highest percentage of clay is in sample L, Table II, which is the boulder clay, and generally the soils on boulder clay have the higher clay content, but even the clayey content of the soils on the glacial gravel may be fairly high.

E is such a soil and should be compared with C, also taken from a gravel-spread, but in this case the clay content is low while the coarse sand fraction is high. The soils on the glacial sand and gravel-spreads are very variable in texture because of the varied nature of the deposit.

MECHANICAL ANALYSIS.

TABLE II.

	A	B	C	D	E	F
Coarse sand	22.86	14.20	36.65	25.02	15.77	25.99
Fine sand	32.29	30.16	32.29	35.63	26.67	31.52
Silt	11.58	16.05	6.28	8.00	11.86	9.00
Fine silt	12.89	15.79	7.18	9.48	10.74	10.64
Clay	10.41	14.07	7.50	11.40	14.88	9.86
Moisture	2.78	2.59	3.79	2.53	4.41	4.84
Ignition Loss	7.11	7.16	6.39	7.43	15.91	8.89
Total	99.92	100.02	100.08	99.49	100.24	100.74

	G	H	I	J	K	L
Coarse sand	24.89	17.31	20.86	16.16	26.83	23.88
Fine sand	31.38	21.70	26.44	28.56	28.52	27.54
Silt	11.44	8.82	11.28	8.12	12.05	9.00
Fine silt	12.16	13.36	17.40	9.12	9.92	12.56
Clay	12.82	17.66	11.40	13.08	7.96	20.08
Moisture	2.43	3.79	2.64	5.03	4.91	2.84
Ignition loss	5.62	17.66	9.85	19.35	9.02	4.06
Total	100.74	100.30	99.87	99.42	99.21	99.96

Mineralogical Analysis.

TABLE III.

Results of analyses of fine sand fractions, given as percentages.

No.	Orthoclase group.	Quartz group.	Ferro-magnesian silicate group.
A	6.3	88.3	5.4
B	6.7	78.7	14.6
C	6.6	75.9	17.5
D	8.3	78.0	13.7
E	7.1	86.3	6.6
F	7.9	77.2	14.9
G	4.3	89.2	6.5
H	2.1	89.7	8.2
I	10.25	85.55	4.2
J	7.1	81.7	11.2
K	6.6	75.9	17.5
L	2.2	89.5	8.3

In Table III are given the percentages of the three groups for the soils examined, and the figures should be read in conjunction with Table IV which gives the minerals present other than quartz. In this table the numbers set vertically indicate the frequency of occurrence of the minerals in the soils, 1 meaning most common, 2, 3, 4, etc. indicating decreasing frequency.

TABLE IV.

Mineral suite — other than quartz.

	A	B	C	D	E	F	G	H	I	J	K	L
Plagioclase	2	2	2	3	3	2	1	2	2	3	2	2
Orthoclase & Microcline	4	4	4	5	5	3	5	6	7	6	4	5
Iron Oxides	1	1	1	1	1	1	2	1	1	1	1	1
Augite	3	3	3	2	2	4	3	3	3	2	3	3
Enstatite	-	-	-	-	-	13	-	-	-	-	12	-
Hornblende	6	9	-	-	8	9	7	10	12	9	7	9
Biotite	5	5	5	4	4	5	4	7	6	4	5	6
Apatite	8	-	10	9	11	8	9	8	8	7	-	8
Garnet	9	10	7	6	7	10	8	5	5	5	6	7
Zircon	7	7	6	7	6	6	6	4	4	3	8	4
Tourmaline	11	11	8	10	10	11	11	12	11	8	11	10
Rutile	10	-	-	-	13	-	12	11	9	-	-	12
Chlorite	-	6	-	-	9	7	-	-	-	-	9	11
Glauconite	-	-	-	-	-	12	-	-	-	-	-	-
Rock fragments	12	8	9	8	12	-	10	9	10	10	10	13

<u>DESCRIPTION of MINERALS in the FINE SAND FRACTION of the SOILS.</u>

(see Plate II).

Though there is a great variety of material in the geological sense from which the soils are derived it is interesting to note that there is little variation in the <u>shape</u> of the constituent minerals in all the soils excepting those forming on the screes. That is to say the sub-angular to angular shape of the mineral grains of soils lying on the boulder clay is not very dissimilar to the shape of the grains of the soils on the fluvio-glacial material. The grains in the soils lying on alluvium are more rounded but not markedly so. This would indicate that the alluvial material cannot have travelled far, and, as will be shown later, the mineral suite indicates that it has practically the same mineral composition as the boulder-clay.

<u>Quartz</u> is the commonest mineral present in all the soils. It generally occurs in rather sub-angular grains, but the conchoidal fracture gives rise to angularities. This is most marked in the soils on boulder clay and also on fluvio-glacial material but in the soils found on alluvium the grains tend to be more rounded. Inclusions are quite frequent, the commonest being iron oxides, but fluids are also present and in several cases needles of rutile were noted. Frequently regrowths can be seen on the grains.

Plagioclase felspar. This mineral occurs in all the soils examined and apart from quartz is the most plentiful. It is generally weathered but fresh grains also occur and then they are quadrate in shape. The weathered fragments are turbid from decomposition.

Orthoclase felspar is not nearly so common as plagio-clase but it is present in all the soils examined. It occurs in quadrate grains, which are generally sub-angular to angular but in the soils derived from alluvium they tend to be more rounded. It is unweathered. Allied to orthoclase in chemical composition but differing from it in habit is microcline, which is also present in all the soils but in a very subordinate amount. It is very fresh.

Iron oxides, after plagioclases, are the commonest minerals, magnetite, ilmenite, haematite and limonite all being present. It is difficult to distinguish magnetite from ilmenite microscopically and only grains showing ilmenite weathering to leucoxene were taken to be ilmenite. Leucoxene is rather common and is present in all the soils. Magnetite is the most frequent oxide and the grains are often facetted. Both limonite, the commonest oxide after magnetite, and haematite occur in earthy form.

Augite. After the iron-oxides, augite is the commonest mineral present. It occurs in irregular prismatic grains of variable size. Its colour is usually greenish but the titani--ferous variety is also present, though in subordinate amount, and then the colour is brownish.

Enstatite was found in only two soils and is rare. It is colourless and prismatic in habit.

Hornblende is present in all the soils save C. and D. It occurs in prismatic grains generally small in size, and green in colour. It is fresh.

Biotite occurs in rather ragged plates, which are gene--rally bleached, and is rarely fresh. Rounded grains also occur in the boulder clay. It occurs in all the soils and is dark brown in colour, with spots of iron oxide.

Apatite is infrequent and was not found in all the soils. It occurs in small prismatic grains, often rounded. Its infrequent occurrence in the fine-sand fraction may be accounted for partly by its habit and partly by its ready solubility, which would tend to make it more common in the fine grades.

Garnet occurs in all the soils. It is generally colourless but a pinkish-brown type also occurs. It is angular to sub-angular in shape and is granular.

Zircon is common in all the soils. It is generally prismatic/

prismatic with pyramidal terminations but ovoid grains also occur. It is usually colourless but brownish varieties occur. Inclusions are common.

Tourmaline. This mineral is present infrequently in many of the soils. Brown is the commonest colour but green-brown varieties also occur. Its form is prismatic but the ter-minations are irregular. It is very fresh.

Rutile is also infrequent. It is deep brown in colour and is irregularly prismatic and angular.

Chlorite occurs in certain of the soils as rounded grains, green in colour.

Glauconite. In soil No F a green amorphous mineral was isolated, which from its refractive index, and optical properties suggest glauconite rather than chlorite. Glauconite does not seem to be common in Scottish Carboniferous sandstones and has not been found there by Bosworth (13). Cayeux (18) has suggested that it may be an authigenic mineral in arable soils.

Rock-fragments are matrix-fragments of the local lavas, in certain cases determined as rhyolite, in others as basalt.

MINERALS and PLANT FOOD.

In all the soils examined above, orthoclase, microcline, and biotite were found to occur. Now those are among the most important minerals containing potassium, and their amount and condition of freshness must have much to do with the amount and availability of the potash necessary for plant food. Of the Boghall soils then it may be said that potash is present in fair amount, but that since biotite is the only potash-bearing mineral present in a weathered state the availability of the potash may be low.

In the majority of the soils examined apatite was de--tected, although in small amount, and it may be present in the other soils, since it is readily soluble. It is the only phos--phate-bearing mineral in the soils.

The main lime-bearing minerals are plagioclase, augite and hornblende. The plagioclase occurs as quadrate grains which are mainly weathered, although fresh grains do occur. Augite and hornblende are generally fresh. Garnet, though lime-bearing, is not easily decomposed, and is fresh.

SOILS on the SCREE MATERIAL.

Sample I of Table IV is a soil taken on the hill-wash of the acid belt of rock on Caerketton Hill, but from the nature of the mineral suite it will be seen that glacial material must be intermixed. The percentage of the ferro-silicate group is lower than that of the soils derived from drift material, but the mineral suite is not very different. In a soil lying on the top of Caerketton Hill the heavy residue was too small to be measured, but zircon, garnet, rutile, and tourmaline were present along with augite and iron oxides. The main mass of the fine sand fraction was made up of rock fragments (rhyolite) with quartz grains. This would indicate that the ice had swept completely over the hills and that a wash of material had been laid down and then mostly removed by denudation.

In a soil formed on the scree to the south of Allermuir Hill the fine sand fraction was found to consist of about 60 per cent of quartz, the remainder being mainly composed of rock fragments, plagioclase, iron oxides, augite. The minerals were all heavily stained with iron oxides. In a similar soil on Caerketton Hill the same constituents were present in the same condition but the proportions were different, the quartz percentage being much higher.

The minerals of the soils on the screes are very angular and/

and the soils differ from those on the drift material in having a large content of rock fragments.

RELATION of SOILS to the DRIFT MATERIAL.

Sample L in Table IV is an analysis of the boulder clay, as found in the glen. It represents horizon C of the surface soil, sample G. From the mineral suite it will be seen that its content resembles the content of the surface soil, and apart from slight differences in frequency, the content of all the soils lying on glacial drift (whether boulder clay or fluvio-glacial material) and alluvium is practically identical. This indicates a similarity in origin. The interesting question of the origin of the matrix of the boulder clay is also raised.

The alluvium from its situation cannot have travelled far, and both the physical characters of the grains, which are sub-angular rather than rounded, and the mineral suite point out its local origin by denudation of the boulder clay. It is mainly over boulder clay that the stream runs.

Of the minerals in the boulder clay the predominant, apart from quartz, are iron oxides, plagioclase, biotite, augite. All these minerals are found in the local lavas as are also horn-blende, apatite and chlorite, which occur in subordinate amount in the boulder clay. Zircon also occurs in the local lavas, but the/

the zircons in the soils are probably too numerous, and in many cases too large to be local. Of the minerals present, which can definitely be said not to be local, are the following: zircon, garnet, tourmaline, rutile, enstatite. These minerals may be formed from the disintegration of boulders of Highland rocks carried from the north-west by the ice, but they may also be de--rived from the sandstones of the Carboniferous formation to the north-west of the Pentland Hills, since Bosworth (12) has found them present in Carboniferous sandstones. The matrix of the boulder clay may, therefore, be said to be mainly made up of material derived by the disintegration of local rocks. The soils of the farm may be definitely linked to the underlying rocks through the boulder clay. The character of the erratics may serve only as an indication of the direction from which the ice has come and may not indicate the nature of the drift matrix.

The geological nature of the materials from which the soils of the Experimental Farm have been formed, has had a marked effect on the texture of the soils. This is well seen in the great variability of the soils lying on the gravel-spread to the south of the road. The boulder clay soils are the heaviest while the alluvium gives rise to soils of a silty character.

In comparing the mineral suite of the soils with those obtained/

obtained by Hendrick and Newlands (5), it will be seen that while the state of freshness and general physical character of the grains agree with those derived from the Old Red Sandstone forma--tion, the mineral suite is more allied to that of the soils on the Carboniferous formation. This may be partly explained by the lithological variation in the Old Red Sandstone formation, in that the Old Red Sandstone of the farm area is composed of lavas, while in the areas examined by Hendrick and Newlands sandstone and flagstones predominate.

PART III:

THE PETROLOGY OF CERTAIN BOULDER CLAYS OF KINCARDINESHIRE.

The results of the previous studies on the soils of south-east Scotland indicated that the mineral composition of the glacial drifts approximated to that of the underlying rock formation. The geology of the area is fairly simple and the rock formations uniform and extensive. It was thought advis-able to continue the study in an area of more complex geology and to study the boulder clays before the soils. The following account is only to be regarded as preliminary since the study is not yet completed.

Such an area is Kincardineshire, for, not only is the solid geology complicated but at least three ice movements with three consequent boulder clays have been detected. The area has long been studied by glaciologists and in recent years intensive-ly by Dr. Bremner (19, 20). These three clays will be referrd to as the Lower, the Middle, and the Upper respectively. The first was laid down by ice moving from the north-west to south-east, the second by ice moving from the south-west to north and the third moved in a direction similar to the first. It is not to be expected, therefore, that the first and the third clays will differ/

differ much, save that the third clay may incorporate material derived from the second. No detailed petrological examination of a Scottish boulder clay has so far been made and the differen--tiation of these clays has generally been made on the erratics in them.

GEOLOGY.

The geology of the area is described in Sheets 67 and 77 of the Geological Survey of Scotland. The following rock groups occur:

Old Red Sandstone	Lower.
Silurian	(Downtonian).
Upper Cambrian (?)	(Highland border rocks).
Metamorphic series	(Schists, gneisses).
Intrusive igneous rocks	(granites, epidiorites).

The first three groups are separated from the last two by the Highland boundary fault. The Highland border rocks con--sist of lavas and altered siliceous sediments while the Down--tonian series is made up of breccias, sandy mudstones and sandstones. These are succeeded by the Old Red Sandstone group, which consists of conglomerates, sandstones and marls, inter--bedded with lavas and tuffs.

North of the fault lie a series of metamorphic rocks, schists of various types and gneisses. These are intruded by granites and by epidiorites.

Overlying all these are the glacial deposits, boulder clay, laminated clays, glacial sands and gravels.

DESCRIPTION of BOULDER CLAYS sampled.

Samples of all three boulder clays were obtained from various parts of the county and an account of these is given in Table I. The colour of the clays varies according to the locality. In the Old Red Sandstone areas the Lower clay is red-dish brown (as at Inverbervie and Catterline) while north of the fault over the metamorphic series the colour is greyish brown (Mill of Forest), and in the northern part (Nigg Bay) it is grey. There is not so much variation in the samples collected of the Middle clay. They are generally reddish brown. Only one sample of the Upper Clay has been examined yet: it is grey brown in colour.

It is not yet certain that Nos. 9 and 10 clays are boulder clays. The results have indicated that No. 10 is most probably not a boulder clay. They are both blue grey in colour but No. 9 is very shelly whereas there are no shells in No. 10.

TABLE I.

	Sample	Location	Description	Underlying rock formation
Group I.	1	Inverbervie	(?)Lower boulder clay	Old Red Sandstone
	2	Catterline	Lower boulder clay	Old Red Sandstone
	3	Mill of Forest	Lower boulder clay	Downtonian
	4	Bay of Nigg	Lower boulder clay	Metamorphic Series
Group II.	5	Stonehaven Harbour	Middle boulder clay	Old Red Sandstone
	6	Mill of Forest	Middle boulder clay	Downtonian
	7	Bay of Nigg	Middle boulder clay	Metamorphic Series
Group III	8	Balnagask	Upper boulder clay	Metamorphic Series
Group IV.	9	Bridge of Dee	Shelly blue clay	Metamorphic Series
	10	Gourdon	Blue clay	Old Red Sandstone

MECHANICAL ANALYSES.

The mechanical analyses of the boulder clays were carried out by means of Crook's elutriator (21). The material was air dried, sieved through a 1 m.m. sieve and the analysis carried out on the material passing through the sieve. The re--sults are given in Table II.

TABLE II.

	Group I.			Group II.			
	1	2	3	4	5	6	7
Coarse sand	22.71	24.88	15.52	27.25	16.65	19.94	21.06
Fine sand	15.69	11.53	21.32	8.17	17.49	15.46	11.40
Silt	35.57	37.30	27.18	32.46	33.48	29.39	14.22
Clay	26.03	26.29	35.98	32.13	32.38	35.21	53.32

	Group III.	Group IV.	
	8	9	10
Coarse sand	30.74	10.42	12.07
Fine sand	12.60	17.31	19.04
Silt	30.99	41.58	50.53
Clay	25.67	30.69	18.36

All the boulder clays are very stoney, in every case the sample being made up of over thirty per cent of stones. Only in Nos. 9 and 10 was there less than 10 per cent.

The clay and silt content of the Lower boulder clays are fairly consistent while there is much variation in those of the Middle boulder clays. In the Shelly blue clay and the Gourdon blue clay there is a very high silt percentage.

MINERALOGICAL ANALYSIS.

The separation of the minerals of the fine sand frac--tion into two groups was carried out as before, the light group containing quartz and feldspar, and the heavy group the ferro-magnesian silicates and iron oxides. The results of the analysis are given in Table III. It will be noted that the ferro-magnesian silicate percentage in practically every case is much higher than that of the boulder clay (No. L, Pt. II., p. 42) of the south-east Scotland. This is due to the fact that the ice has been mainly moving over a belt of metamorphic and igneous rocks.

MINERALOGICAL ANALYSIS.

TABLE III.

Results of analyses of fine sand fractions, given as percentages.

No.	Quartz and Feldspar group.	Ferro-magnesian silicate group.
	Group I.	
1	86.8	13.2
2.	84.1	15.9
3	89.5	10.5
4	79.9	20.1
	Group II.	
5	85.5	14.5
6	78.4	21.6
7	81.9	18.1
	Group III.	
8	86.8	13.2
	Group IV.	
9	89.7	10.3
10.	93.1	6.9

TABLE IV.

Mineral suite, other than quartz and feldspar.

	Group I.			Group II.				Group III.	Group IV.	
	1	2	3	4	5	6	7	8	9	10
Iron oxides	1	1	3	2	1	1	1	3	1	2
Augite	7	5	-	14	9	2	-	-	-	9
Enstatite	-	-	-	-	12	-	-	-	-	8
Hypersthene	11	-	-	13	-	8	-	10	8	7
Diopside	-	9	-	-	-	11	-	-	-	14
Hornblende	3	2	5	1	4	6	5	5	4	3
Actinolite	-	13	13	11	-	12	-	7	9	16
Sillimanite	-	-	10	7	13	-	11	9	-	13
Andalusite	-	-	-	11	-	-	-	-	-	-
Biotite	6	3	1	3	3	4	2	1	2	4
Muscovite	4	4	2	5	5	5	3	4	3	5
Chloritoid	-	-	12	-	-	-	-	-	-	-
Epidote	12	7	8	6	8	-	9	6	13	6
Zoisite	-	-	9	10	-	-	-	-	-	17
Staurolite	10	11	6	8	-	9	8	12	6	10
Kyanite	13	8	-	12	-	-	10	-	7	12
Apatite	8	-	-	-	7	-	-	-	12	11
Garnet	2	6	4	4	2	3	4	2	5	1
Zircon	5	-	-	8	6	-	6	11	10	-
Tourmaline	9	10	7	9	10	7	7	8	11	15
Rutile	-	-	-	-	11	10	-	-	-	-
Corundum	-	-	11	-	-	-	-	-	-	-
Chlorite	14	12	-	-	-	-	-	-	-	-

DESCRIPTION of MINERALS.
(See Plate III).

In Table IV are given lists of the minerals found in the heavy group of the fine sand fraction of the clays.

The minerals are marked — in contrast to the soil minerals previously studied — by their relatively large size and also by their freshness. The grains tend to the maximum size in the fine sand grade and there is not the admixture of sizes previously found. The grains are also remarkably angular in all the clays apart from No. 10, where the grains are well rounded suggesting that the grains have been water worn. Probably this clay is not a boulder clay.

Quartz is the commonest mineral present. Plagioclase, orthoclase and microcline are present in all the clays, the two former turbid but the latter is generally fresh.

Iron-oxides. Ilmenite and magnetite are the commonest iron-oxides present and are common in all the clays. Limonite and haematite are also present and leucoxene derived from ilmenite has also been noted.

Augite occurs in greeny brown prisms, stout and angular. The prism ends are generally frayed and the grains slightly decomposed.

<u>Enstatite</u> is uncommon. The grains are colourless, prismatic, with a good cleavage along the length.

<u>Hypersthene</u> is not common. The grains are prismatic with irregular terminations and show the characteristic pleochroism.

<u>Diopside</u> is uncommon. The grains are colourless, prismatic, with a cleavage developed along the length.

<u>Hornblende</u>. Brown, greeny brown, green and blue green varieties have been noted. The extinction angle also varies among the different types. The grains are large, very fresh and prismatic. Probably several varieties of amphiboles are present.

<u>Actinolite</u> is fairly infrequent. The grains are grey--ish green in colour, very slightly pleochroic and exhibit frayed ends.

<u>Sillimanite</u>: Individual crystals and fibrous aggregates have both been met with. It is greyish with irregular terminations

<u>Andalusite</u> has only been noted in clay No. 4. It occurs in stout prismatic grains, colourless with a distinct pleochroism.

Biotite and Muscovite are both very common. The biotite occurs as rather large ragged plates, green and brown in colour. Pleochroic haloes are common. Muscovite occurs in rounded colourless plates.

Chloritoid is very infrequent and has only been noted in clay No. 3. It occurs in fairly thick triangular plates, showing the basal cleavage, and a cleavage at right angles to this. The pleochroism is from olive green to green. The grains are rather small.

Epidote is present in nearly all the clays, but in varying amounts. It is very common in No. 10. The grains are generally slightly rounded, yellow green in colour and with a fairly good pleochroism. The form is irregular.

Zoisite is very infrequent. The grains are small, irregular in shape but with a tendency to be prismatic. The grains are colourless.

Staurolite was noted very frequently. It occurs in fairly large, rather rounded grains with a yellow brown colour, and distinctly pleochroic.

Kyanite is uncommon. The grains are large, prismatic with a marked cross cleavage.

<u>Apatite</u> is rather rare. The grains are clear, pris-matic with rounded terminations or completely rounded.

<u>Garnet</u>. Colourless, pinkish and pinkish brown variet-ies have all been noted. The grains are large, irregular and occasionally show an imperfect cleavage.

<u>Zircon</u>. The zircons vary in form, crystalline types and prismatic with rounded terminations have both been seen. The grains are occasionally large and inclusions are common. Zoned varieties are also present.

<u>Tourmaline</u> occurs in brown and pinkish brown grains, prismatic in habit. Broken grains are common.

<u>Rutile</u> is rare. The grains are foxy red in colour, irregular, with prismatic habit.

<u>Corundum</u> occurs in tabular grains, blue in colour.

<u>Chlorite</u> occurs in rounded green grains.

DISCUSSION of RESULTS.

The mineral suites of clays 1 and 2 of Group I. are similar and the relative frequency of the minerals in each is practically identical. The only difference is that in No. 2 there is the occurrence of actinolite and diopside. Both these clays overlie Old Red Sandstone rocks but No. 2 is much nearer the metamorphic rocks than No. 1. The mineral suite is such as could be derived from the underlying rocks. The association of garnet, augite, hypersthene, hornblende is noteworthy.

Mineral suite No. 3 differs from the preceding two in the increase of such minerals as the micas and the presence of sillimanite, chloritoid, zoisite and corundum and the non-occur--rence of augite. The boulder clay overlies Downtonian rocks but the metamorphic series from which most of these minerals listed were derived, lies immediately to the north-west. There would seem to be an overlap of the boulder clay here.

Clay No 4 has also a similar suite to No. 3 but horn--blende is much commoner. The minerals of the metamorphic series are also important in this suite. The clay overlies a belt of metamorphic rocks.

The above results would indicate a variation in the mineral content of the Lower boulder clay according to the rock formations over which the ice has travelled.

In the mineral suite of Group II., i.e. of boulder clays laid down by the ice moving from south-west to north there is a resemblance to that of clay No. 1 of Group I. As a whole there is a decrease in hornblende and also in minerals such as sillimanite, actinolite, diopside, and kyanite.

Nos. 5 and 6 overlie rocks of Old Red Sandstone age and the mineral suite is such as would be expected, minerals such as sillimanite probably being incorporated from the Lower clay. The presence of augite is a noteworthy feature of these clays. In No. 7 there is a marked increase compared with No. 5 and No. 6 of the metamorphic minerals, augite being absent. The clay here overlies the metamorphic series. Rutile has only been recorded from this group.

Only one sample of the Upper Clay of Group III being available no generalisation can be made from the mineral analysis. The mineral suite shows the abundance of micas, garnet, hornblende and the occurrence of such minerals as actinolite, sillimanite, and staurolite. The iron oxides are not so abundant as in the other clays. The mineral suite is such as would be given by the grinding down of the metamorphic rocks of the district by the ice.

The exact relations of the clays Nos. 9 and 10 of Group IV to the other boulder clays has not yet been determined. The clays differ not only in the angularity of the grains, those in No. 10 being much more rounded than No. 9 but they differ also in the mineral suite. No. 10 is characterised by the abundance of garnets and also by the presence of augite, enstatite, diopside, sillimanite, zoisite, which have not been recorded from No. 9. No shelly fragments such as characterise No. 10 have been found in No. 9.

The results of the petrological examination of the matrix of the boulder clays have indicated a variation in the mineral content according to the rock formation traversed by the ice and also that the Lower and Upper clays can be differentiated from the Middle by this means. The examination of the coarser material of the boulder clays which is still in progress has, however, indicated that much of it has been transported for some distance. This is very marked, for instance, in the Middle boulder clay of Mill of Forest, in which marls derived from the Howe of Mearns are common. The determination of the petrological character of the finer material, however, gives valuable information as to the genesis of the boulder clays even in a region of complicated geology.

REFERENCES.

1. Glinka, K. (1914), Internat. Revue of Science and Practice of Agr. New Series, 2, No. 1.

2. Hall, A. D. and Russell, E. J. Agriculture and Soils of Kent, Surrey, and Sussex, (1911).

3. Rigg, T. J. Agric. Sci. (1916), 7, 385.

4. Hendrick, J. and Newlands, G. J. Agric. Sci. (1923), 13, 1.

5. Do do J. Agric. Sci. (1925), 15,257.

6. Ogg, W. G. Proc. Internat. Soc. Soil Sci. Washington, (1928).

7. Loos, H. Bijdrage tot de Kennis van eenige Bodemsoorten van Java en Sumatra (1924).

8. Memoirs of the Geological Survey of Scotland: The Geology of the Neighbourhood of Edinburgh.

9. Memoirs of the Geological Survey of Scotland: The Geology of East Lothian.

10. Gracie, D. S. The Mechanical Analyses of some Scottish Soils. Proc. First Internat. Soc. Soil Sci. Washington. (1928).

11. Plummer, J. K. Journ. Agric. Res. 14, No. 8, p. 297.

12. Bosworth, T. O. Proc. Geol. Assoc. (1913), 24, 57.

13. McCallum, A. Cambridge County Geographies: Midlothian (1912).

14. Bennie, J. Proc. Roy. Phys. Soc. Edin. (1883), 7, 307.

15. Smith, A. M. J. Agric. Sci. (1925), 15, 466.

16. Ogg, W. G. and Dow, W. T. J. Agric. Sci. (1928), 18, 131.

17. Agric. Progress (1926), 3, 106.

18. Cayeux, L. Ann. Soc. Géol. du Nord (1905), 34, 146.

19. Bremner, A. Trans. Edin. Geol. Soc. (1925), 11, 25.

20. Do Trans. Edin. Geol. Soc. (1928), 12, 147.

21. Crook, T. Economic Mineralogy (1921).

EXPLANATION OF PLATES.

PLATE I.

Photomicrographs of soil minerals.

(Ord. light x 35).

Fig. 1. Soil 17. Palagonite fragments. The lighter grain is orthoclase.

Fig. 2. Soil 7. Iron-oxides, augite, biotite, epidote, staurolite, garnet, tourmaline.

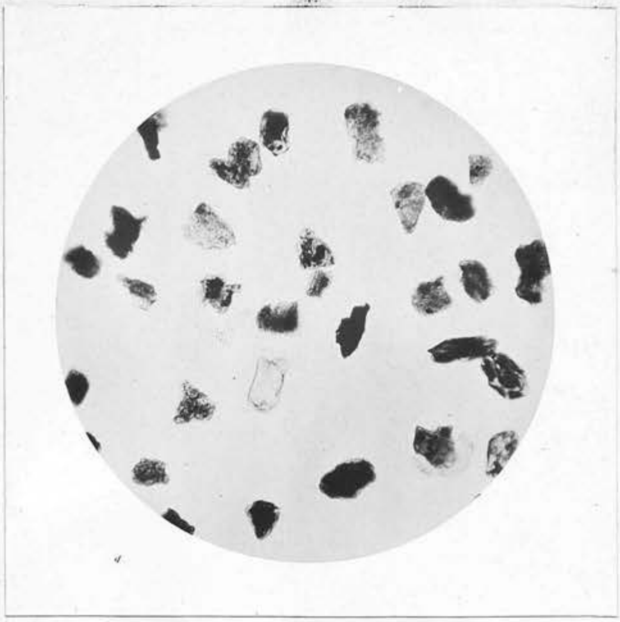
Fig. 3. Soil 8. Iron-oxides, augite, hornblende, staurolite, garnet, tourmaline.

Fig. 4. Soil 12. Iron-oxides, augite, apatite, zircon.

Fig. 5. Soil 23. Iron-oxides, augite, hypersthene, hornblende, biotite, muscovite, zircon, rutile.

PLATE I.

1.



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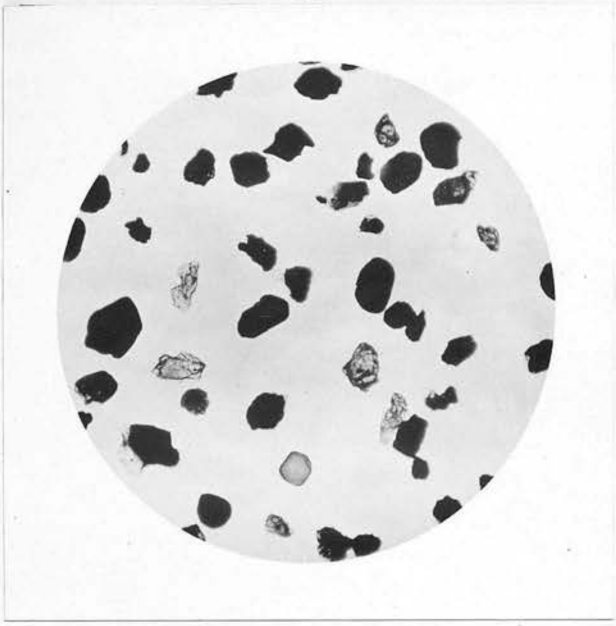

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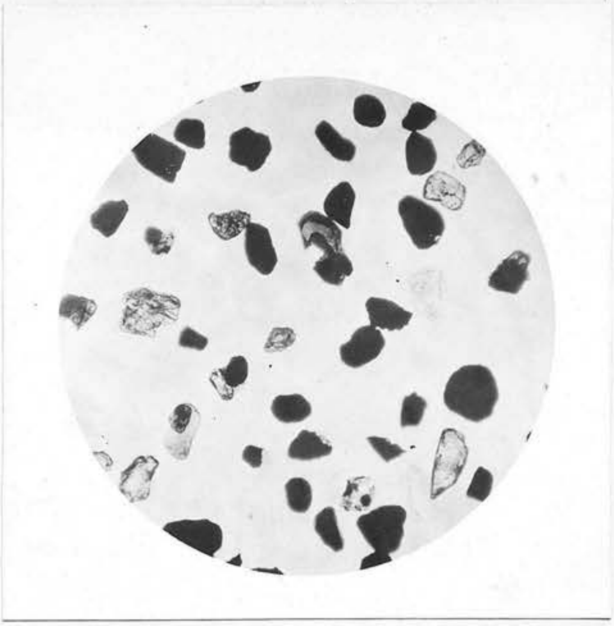

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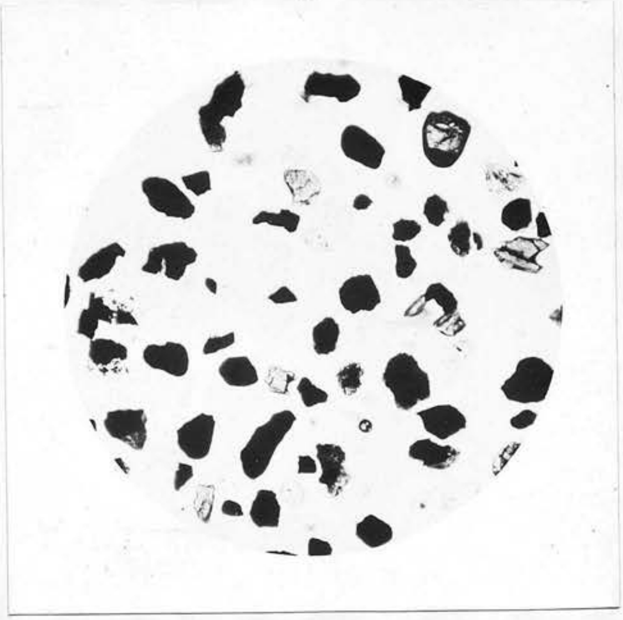


5.

PLATE II.

Photomicrographs of minerals of soil G, Pt. II.

Fig. 1. Quartz and plagioclase grains.

(Ord. light x 35 diam.).

Fig. 2. Orthoclase grains. The dark grains are rock fragments.

(Ord. light x 35 diam.).

Fig. 3. Heavy residue. Minerals shown are iron-oxides, augite, hornblende, zircon, apatite, garnet and tourmaline.

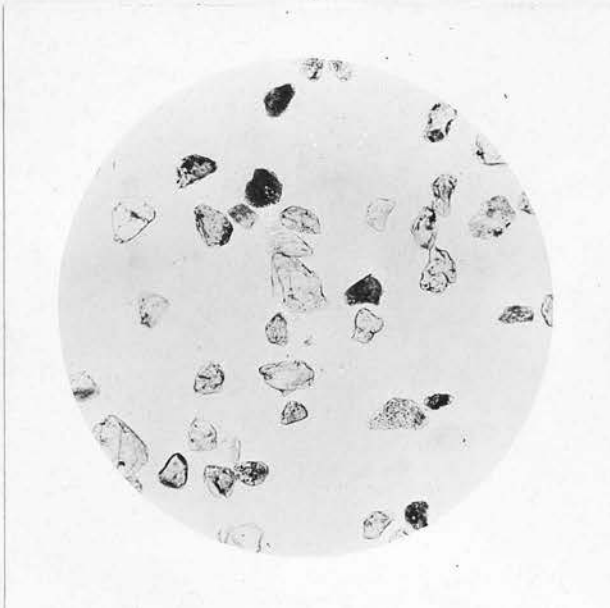
(Ord. light x 35 diam.).

Fig. 4. A. Augite, B. Biotite. C. Hornblende. D. Tourmaline. E. Zircon. F. Garnet.

(Ord. light x 90 diam.).

PLATE II.

1.



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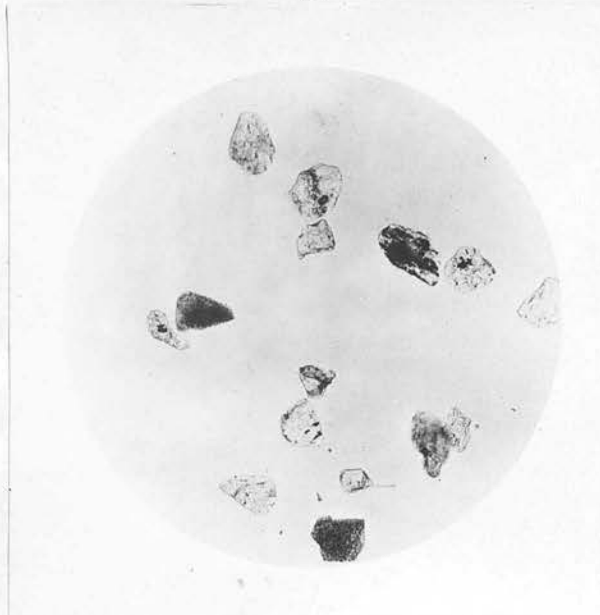

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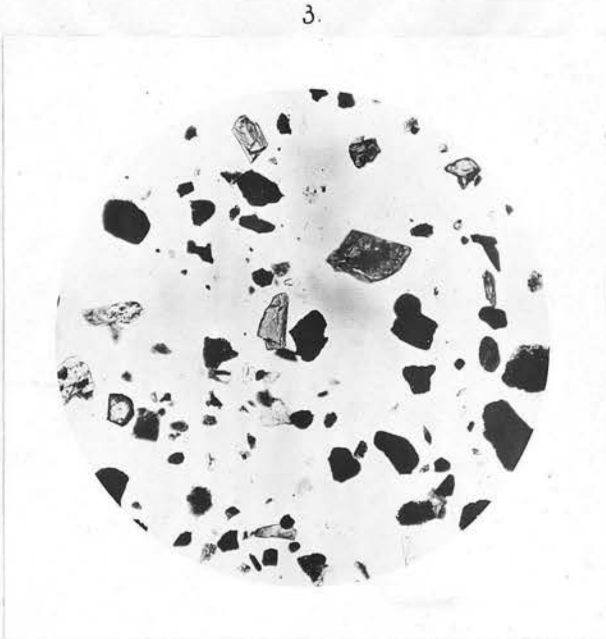


4.

PLATE III.

Photomicrographs of minerals

from boulder clays of Kincardineshire.

(Ord. light x 40 diam.).

Fig. 1. Lower boulder clay: Mill of Forest.

Iron-oxides, hornblende, biotite, muscovite, chloritoid, garnet.

Fig. 2. Middle boulder clay: Mill of Forest.

Iron-oxides, augite, hornblende, biotite, rutile, garnet.

Fig. 3. Upper boulder clay: Balnagask.

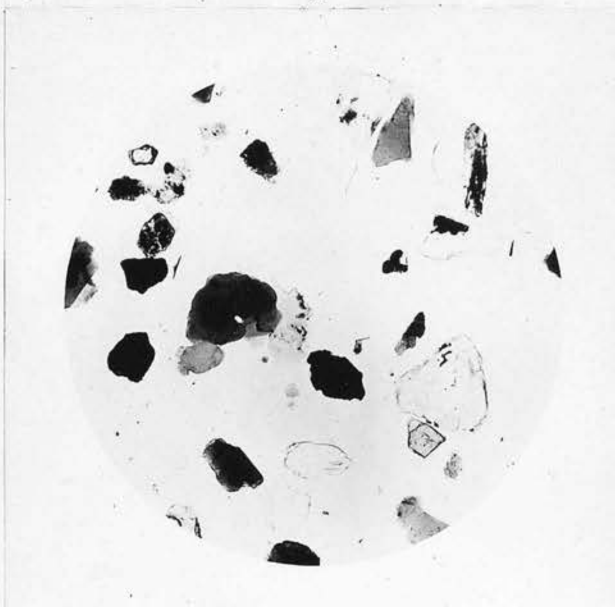
Iron-oxides, hornblende, actinolite, biotite, muscovite, garnet, tourmaline.

Fig. 4. Blue clay: Gourdon.

Iron-oxides, augite, hypersthene, hornblende, apatite, biotite, muscovite, epidote, garnet.

PLATE III.

1.



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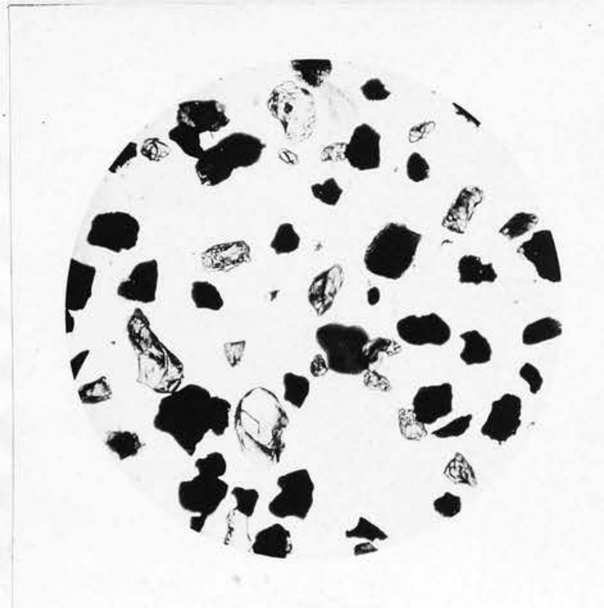

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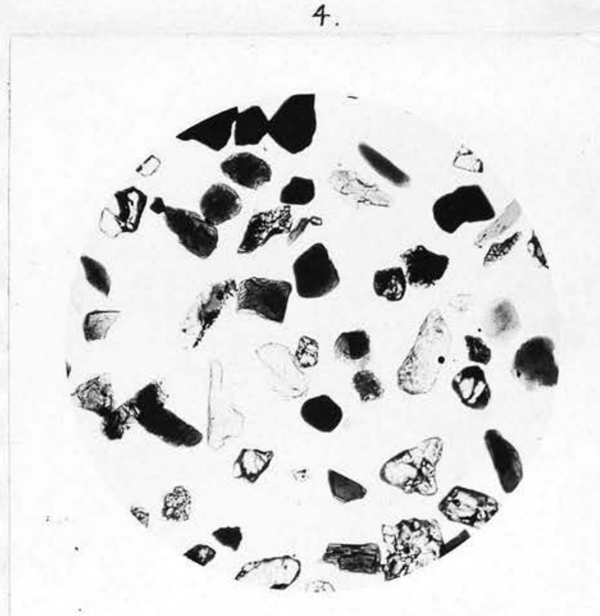


Map showing location of soils studied.

(Scale: 1 in. = 4 mls.).

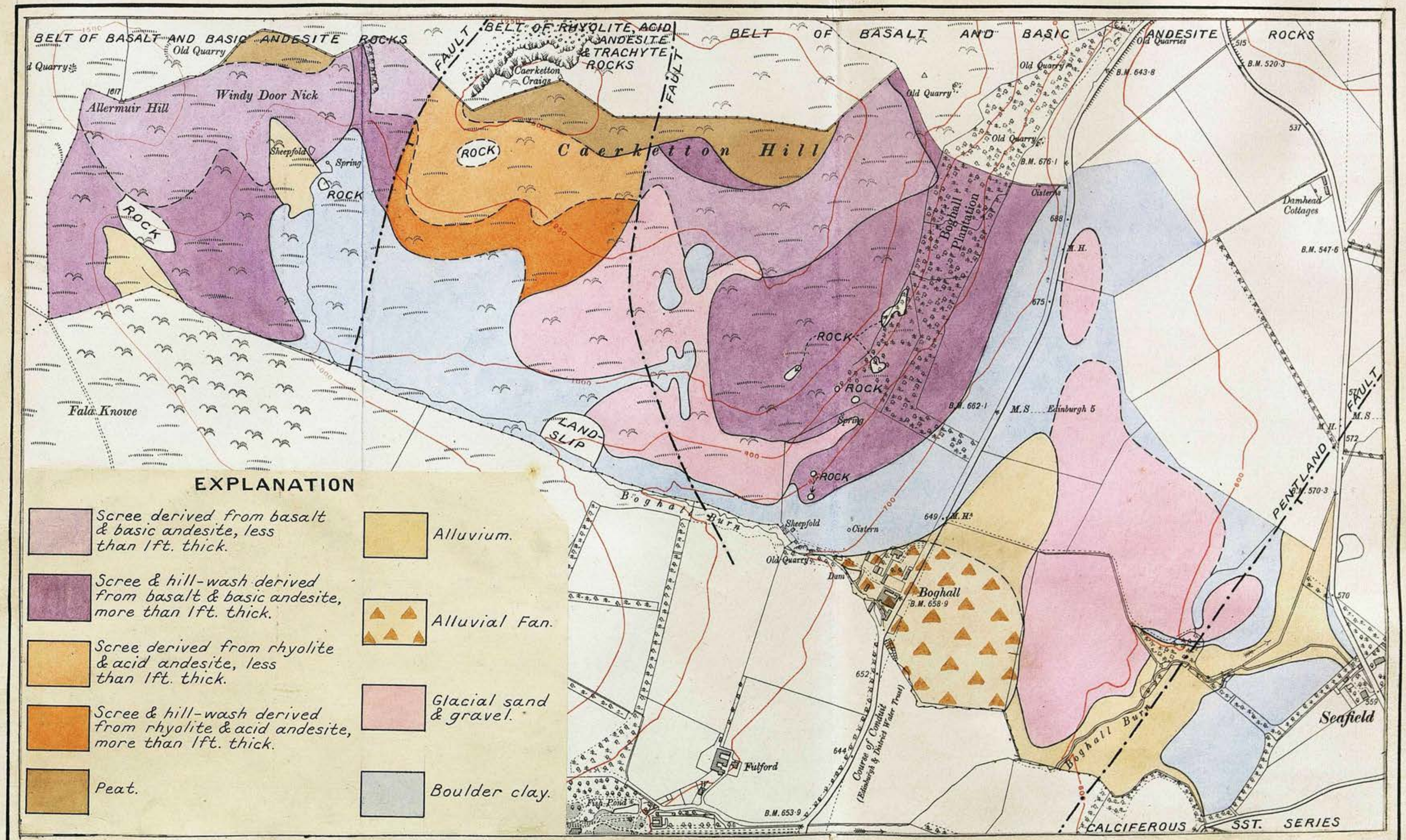
FIRTH OF
HADDINGTONSHIRE
EDINBURGHSHIRE
BERWICKSHIRE
PEEBLESSHIRE
SELKIRKSHIRE
LINLITHGOWSHIRE
ROXBURGHSHIRE
DUNFERMLINE
KINGHORN
BURNTISLAND
INVERKEITHING
NORTH BERWICK
DUNBAR
LEITH
PORTOBELLO
EDINBURGH
PRESTONPANS
MUSSELBURGH
HADDINGTON
DALKEITH
PEEBLES
LAUDER
GALASHIELS
SELKIRK
MELROSE
KELSO
JEDBURGH
GREENLAW
DUNS
COLDSTREAM
BIGGAR
LAMMERMUIR HILLS
PENTLAND HILLS
MOORFOOT HILLS
ETTRICK FOREST
Bass Rock Lighthouse
Inchkeith
St. Mary's Loch

Map of geology (drift and solid) of

Experimental Farm, Boghall, Midlothian.

The lines showing solid geology are taken from maps of Geological Survey of Scotland.

(Scale: 6 ins. = 1 ml.).


BELT OF BASALT AND BASIC ANDESITE ROCKS
BELT OF RHYOLITE, ACID ANDESITE & TRACHYTE ROCKS
BELT OF BASALT AND BASIC ANDESITE ROCKS
FAULT
FAULT
Old Quarry
Caerketton Craigs
Allermuir Hill
Windy Door Nick
Sheepfold
Spring
ROCK
ROCK
ROCK
Caerketton Hill
Old Quarries
Old Quarry
Old Quarry
Old Quarry
B.M. 643·8
B.M. 520·3
B.M. 676·1
Cisterns
Boghall Plantation
Damhead Cottages
B.M. 547·6
M.H.
ROCK
ROCK
ROCK
Spring
B.M. 662·1
M.S. Edinburgh 5
Fala Knowe
LAND-SLIP
Boghall Burn
Sheepfold
Cistern
Old Quarry
Dam
Boghall
B.M. 658·9
Course of Conduit (Edinburgh & District Water Trust)
Fulford
Fish Pond
B.M. 653·9
PENTLAND FAULT
Boghall Burn
Seafield
CALCIFEROUS SST. SERIES
EXPLANATION
Scree derived from basalt & basic andesite, less than 1ft. thick.
Scree & hill-wash derived from basalt & basic andesite, more than 1ft. thick.
Scree derived from rhyolite & acid andesite, less than 1ft. thick.
Scree & hill-wash derived from rhyolite & acid andesite, more than 1ft. thick.
Peat.
Alluvium.
Alluvial Fan.
Glacial sand & gravel.
Boulder clay.